Arctic Upper Ocean Studies

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Contract Number N0001496C0032
http://www.onr.navy.mil/sci_tech/ocean/onrpgahl.htm

LONG-TERM GOALS

My goals are to investigate and understand the turbulent transfer of momentum, heat, salt, and other scalar contaminants in naturally occurring boundary layers of the ocean, and to apply this knowledge to understanding air-ice-ocean interaction in polar regions.

OBJECTIVES

Objectives include interpreting a substantial body of turbulence data from the ocean boundary layer (OBL) under sea ice to better understand (i) the impact of ice-ocean interaction on the heat and mass balance of sea ice; and (ii) general characteristics of ocean boundary layers in response to surface stress, buoyancy flux, and existing temperature/salinity structure. An important element is developing realistic parameterizations of surface (ice/ocean) fluxes in terms of prognostic variables typically carried in large scale models of ocean circulation. An additional important objective is continued development of techniques for measuring turbulence in ocean boundary layers.

APPROACH

I have developed systems for measuring vertical turbulent fluxes of momentum, heat, and salt in the ocean boundary layer under drifting sea ice by direct covariance of the respective quantities with vertical velocity. Three axis current meters are mounted near Sea-Bird temperature and conductivity sensors in turbulence instrument clusters mounted at several levels on rigid masts. The masts may then be lowered to any level within the upper 120 m of the ocean. The turbulence measurements, nearly unique for ocean boundary layer environments, are then used to determine properties and scales of OBL turbulence.

WORK COMPLETED

Work completed in FY 2001 includes:

1. SHEBA data analysis. At the SHEBA Phase III PI meeting in Boulder (July 10-12, 2001) a strategy was developed for producing a “canonical” data set for the SHEBA drift, which would include easily accessible data useful for forcing and comparing numerical model results. I agreed to coordinate the oceanographic aspect, and have to date assembled Matlab data structures containing (a) 3-h bin averaged data for the turbulence mast for periods with currents suitable for covariance calculations; (b)

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 2001**	2. REPORT TYPE	3. DATES COVERED **00-00-2001 to 00-00-2001**

4. TITLE AND SUBTITLE **Arctic Upper Ocean Studies**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **McPhee Research Company,,450 Springs Road,,Naches,,WA, 98937**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S)
	11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
My goals are to investigate and understand the turbulent transfer of momentum, heat, salt, and other scalar contaminants in naturally occurring boundary layers of the ocean, and to apply this knowledge to understanding air-ice-ocean interaction in polar regions.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a REPORT **unclassified**	b ABSTRACT **unclassified**	c THIS PAGE **unclassified**	**Same as Report (SAR)**	**7**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

separate structures with 3-h bin averaged profiler temperature and conductivity, along with 3-h bin averaged T/S from multiple levels on the fixed mast for all operational times; (c) developed access routines for the Scripps low-frequency acoustic Doppler profiler; and (d) provided a continuous record of drift position and velocity from multiple GPS sources. This has entailed careful cross calibration of all Sea-Bird Electronics sensors on the turbulence mast and the automated profiler.

2. Fjord boundary layer studies. In collaboration with scientists from UWAPL, University of Bergen, University Courses on Svalbard, and Cambridge University, we staged an experiment aimed at understanding the double diffusive character of heat and salt transfer at the ice/ocean interface during freezing. Lack of ice at our primary target site in Ny Aalesund, Svalvard, forced us to choose a different site on van Mijenfjord, south of Longyearbyen. We were able to successfully measure under-ice turbulence during tidal cycles for several days, with results immediately applicable to the identified questions.

3. False Bottom Studies. I worked with U. Hamburg graduate student D. Notz on modeling the formation and evolution of "false bottoms" that form at the interface between fresh and salt water bordering under-ice concavities in summer. Notz visited the Polar Science Center, UWAPL, during Spring Quarter, including time spent at McPhee Research and with H. Eicken at UAF. He also worked with G. Maykut and G. Worster, who was concurrently visiting UWAPL. Although the project was begun with no particular appreciation of the large scale importance of under-ice fresh water, the work has resulted in both enhanced appreciation of the role of salt transfer in controlling the melting rate at the ice/ocean interface, and identification of a possibly important impact on the summer ice/albedo feedback issue.

4. Boundary-Layer Modeling. During 2001, I worked with scientists from the Naval Postgraduate School on adapting a Large-Eddy Simulation numerical model to conditions observed over Maud Rise in the Weddell Sea thought to be conducive to thermobaric instability. Part of this entailed refining the incorporation of destabilizing surface buoyancy flux in the local turbulence closure (LTC) I use for eddy viscosity/diffusivity ocean boundary layer modeling.

In a separate application of the LTC model, I successfully simulated a diurnal cycle of heating and cooling of the mixed layer under the SHEBA drift station that persisted for several days during June, 1998. Insolation was modeled as a fixed percentage (8%) of incoming shortwave measured at the ice surface, and was attenuated exponentially in the upper ocean with an e-folding depth of 4 m. In addition to temperature, a diurnal cycle in heat flux, with significant vertical structure was also simulated.

RESULTS

In the ONR sponsored MIZEX programs of the late 1980s, we found with the first direct measurements of turbulent heat flux under melting sea ice, that basal melting was rate controlled by the transfer of salt across very thin laminar sublayers, rather than by direct turbulent heat transfer (McPhee et al., 1987). The double-diffusive character of the interface sets important constraints on the overall ice-ocean heat transfer, allowing, for example, the polar mixed layer to warm several tenths of a degree above freezing during summer, even when the ice cover is nearly complete. It turns out that a critical parameter controlling melt rate at the interface is the ratio of exchange coefficients relating fluxes of heat, salt, and momentum to far-field temperature and salinity.

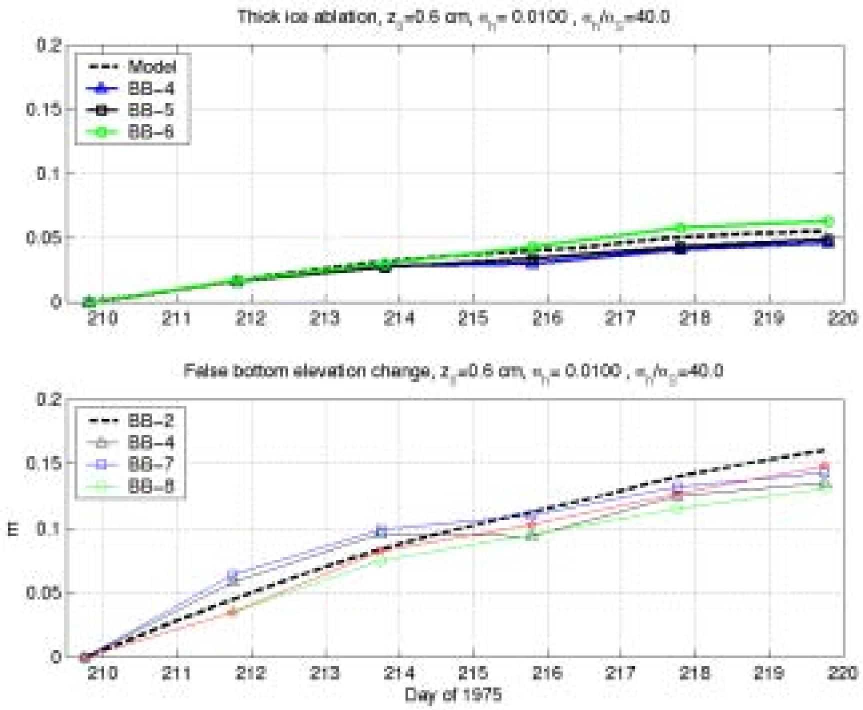

Figure 1 Ablation rate measured at the base of thick ice during the 1975 summer at AIDJEX by Arne Hanson is shown in the upper panel, with results from 3 sites averaging about 6 cm over 10 days. A dashed curve showing results of an interface heat and salt transfer model follows the measured values closely. Similar curves for ablation under false bottoms are shown in the lower panel, averaging around 14 cm in the same span, which is again well reproduced by the model (heavy dashed curve). The change in bottom elevation is 2.5 times larger under the false bottoms.

An unexpected twist to the false bottom investigation was the successful modeling of data from AIDJEX collected by Arne Hanson in 1975 showing rapid upward migration of the false bottoms relative to ablation under nearby thick ice (Fig. 1). The growth rate and upward migration of false bottoms is constrained by the ratio of exchange coefficients (40 in the example), thus careful measurement of false bottom evolution in summer may provide valuable data on this otherwise elusive quantity.

A second important result from the study, illustrated in Fig. 2, is that the heat flux under false bottoms is *downward*, even if the mixed layer is above freezing, because a relatively strong positive thermal gradient exists across the thin ice layer separating the fresh meltwater (at 0 °C) from seawater. A common way of treating ocean heat flux in numerical models is to express the heat flux in terms of a *Stanton number*, relating the aggregate scale heat flux to ice interface friction velocity and elevation of mixed layer temperature above freezing. Results from several studies have shown the Stanton number (bulk heat exchange coefficient) to be relatively uniform (McPhee et al., 1999). However, the false bottom study is showing that if the ice undersurface includes an appreciable fraction of false bottom formation, it can have significant impact on the overall gross heat exchange coefficient between the ice and mixed layer: e.g., in the example shown in Fig. 2, 30% coverage would halve the effective heat transfer coefficient.

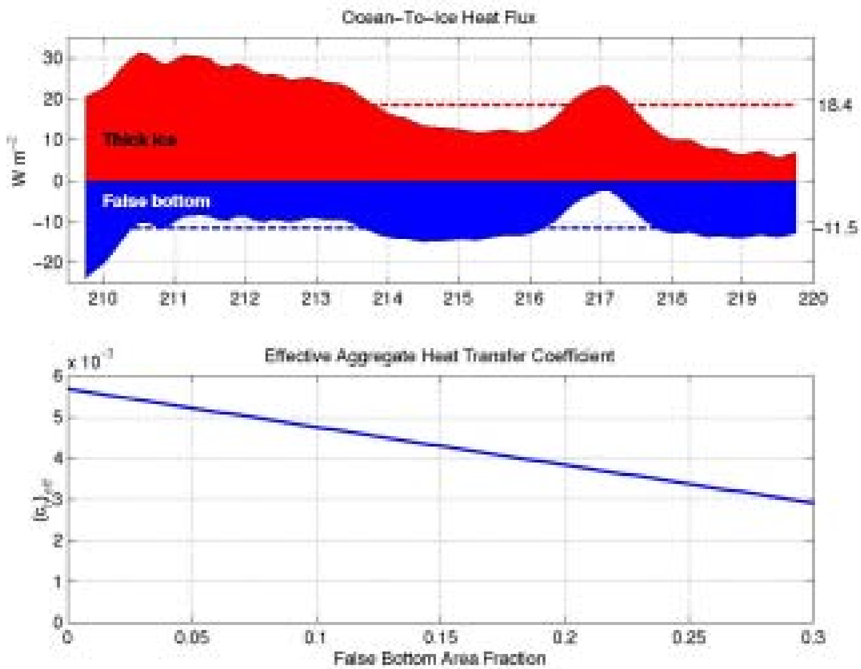

Figure 2 The upper graph shows sensible heat flux from the ice to the ocean, under both thick ice with no false bottoms, averaging 18.4 W m^{-2} (upward) and under a false bottom, averaging –11.5 W m^{-2} (downward). The lower graph shows the aggregate average heat transfer coefficient (Stanton number) as a function of under-ice false bottom area fraction. It decreases from around 0.0056 for no false bottoms to around 0.0029 for 30% coverage.

A closely related question is the impact of double diffusion on heat and salt flux when ice is freezing. If, in fact, the exchange coefficients maintain the large ratio indicated during melting, this would lead to substantial upward heat flux and supercooling of the water column under rapidly freezing ice. The fjord study in Svalbard addressed this specifically. Results (Fig. 3) from measurements in Van Mijen Fjord during March, 2001, are essentially negative. The small mean heat flux measured over current speeds encountered during the tidal cycle, approximately 1.5 W m^{-2}, is approximately that needed to compensate the decrease in freezing point associated with the salt rejected by relatively rapid freezing, with salinity flux ~ -2 psu m s^{-1}. The latter was determined from covariance of vertical velocity and salinity fluctuations measured with a microstructure conductivity sensor. This implies near equality of the kinematic exchange coefficients during freezing.

IMPACT/APPLICATION

Research into basic questions of how the ocean boundary layer works has wide application ranging from detailed studies of ice/ocean interaction to bottom boundary layer flow in estuarine environments to ocean parameterization in global circulation models.

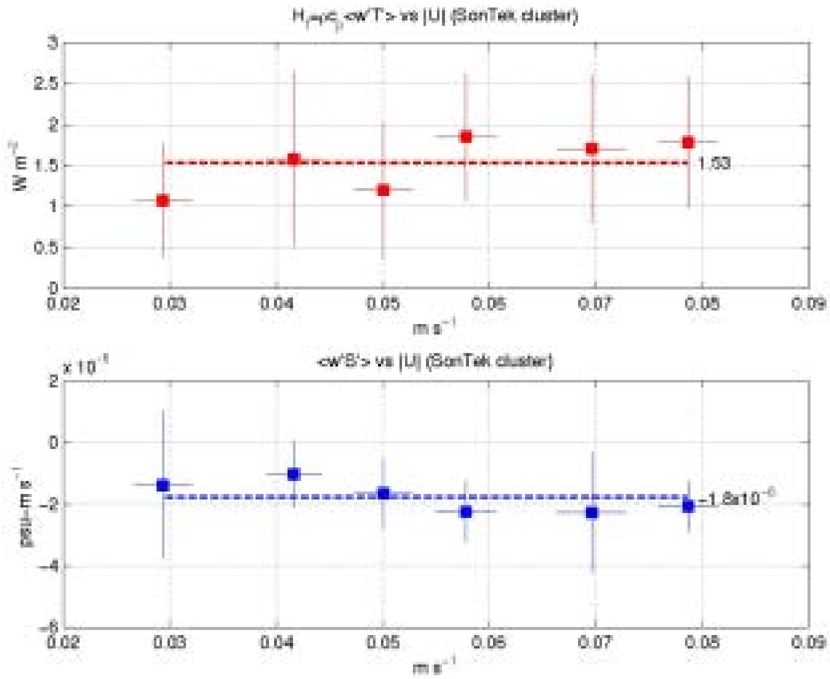

Figure 3 The upper graph shows sensible ocean heat flux in a tidal flow 1 m under fast ice in a frozen fjord as a function of current speed, with standard deviation error bars. There is no dominant trend ,with the average around 1.5 W m^{-2} (upward). The lower graph shows turbulent salinty flux, <w'S'>, as a function of current speed, with no dominant trend and average value of about –2 x10^{-6} psu m s^{-1}.

TRANSITIONS

The SHEBA flux measurements are reshaping many of our views on what controls heat, salt, and momentum exchange between ice and ocean, particularly in summer. These will be incorporated into larger scale models, perhaps with significant impact on our understanding of the ice-albedo feedback issue. Small scale process studies of exchange processes at the ice/ocean interface under both freezing and melting conditions are fundamentally important for understanding the interplay between salt and heat in the formation and destruction of sea ice.

RELATED PROJECTS

I am working with T. Stanton (NPS) on SHEBA analysis and thermobaricity; with B. Garwood and R. Harcourt on thermobaricity; with J. Morison and D. Hayes (UWAPL) on the SHEBA summer leads; G. Maykut (UW), D. Holland (Courant Institute), and W. Maslowski (NPS) on incorporating SHEBA results into ice/ocean models; with C. Bitz, R. Moritz, and M. Holland on incorporating ice-albedo feedback into large scale models; with H. Eicken, D. Notz, and G. Worster on false bottom formation and modeling; with E. Skyllingstad (OSU) on LES model formulation and verification, and with J. Wettlaufer on ice formation processes.

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